Exploring the System Dynamics of Innovation Systems

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Abstract: The innovation system is perceived as an ensemble of resources committed to interrelated innovation activities. The question arising is how the innovation system becomes one (a system), i.e., what are the mechanisms that govern the alignment of resources and activities in innovative directions. A system dynamics framework of analysis is presented where alignment stems from institutional arrangements and strategic intent. These operate as mechanisms of stretch and leverage within an environment of co-opetition and connexity. Central amongst them is the evolution of cognitive-cultural elements that, in the form of mental models (worldviews) and intangible assets (such as trust and co-opeting competence), drive economic action and interaction. A system dynamics modelling approach is proposed that facilitates the quantification and exploration of policy alternatives.

Keywords: innovation systems, systems thinking, system dynamics, resource-based view, institutions, co-opetition, game theory, resource commitment

1 Introduction

The theme of Innovation Systems has proved increasingly prolific, at least in terms of the amount of research, the researchers and the output (in term both of quantity and quality). As a number of projects have come to conclusion (mostly because they have been coordinated and funded by the E.U. programmes and initiatives) a significant number of reviews have been produced (see for example Bartzokas 2000, Edquist 1997, McKelvey 1995). There is a loose agreement on what the common themes are. Edquist (1997, pp 15-29) briefly outlines nine: the central role of innovation and learning, the holistic and interdisciplinary nature of approaches, the acknowledgement of the importance of historical processes, the departure from seeking optimality, emphasis on complexity arising from interdependence and non-linearity, the interrelatedness of technological and organisational innovations, the crucial role of institutions, the emphasis on the articulation of conceptual frameworks rather than formal theories and the common acknowledgement and encouragement of a plurality of perspectives. An evolutionary perspective should be essential in future research as it has also emerged as a common theme (Bartzokas 2000), not completely dissimilar from *inter alia* the notions of historicity and complexity noticed by Edquist.

Edquist (1997) and McKelvey (1991, 1997) stress the divergence in the conceptualisation of institutions and their role. It seems that a majority of analysts have adopted a formal account of institutions (Lundvall 1988, McKelvey 1995). Opposing the formal account of institutions, the approach adopted here follows with those of Lundvall and McKelvey in adopting the 'old-institutionalist' tradition established by Veblen, and restated by Hodgson (1988). In this tradition institutions are products of

'behavioural regularities', evolving in a social context and assuming both formal and informal forms. They include habits and routines, as well as the norms, customs rules and laws that are formed when the former become common to groups of people. In this sense, they govern the behaviour of agents (individual or collective) as well as their interaction (Lundvall, 1992, pp. 25-26). This perspective is compatible with the evolutionary analysis of Nelson and Winter (1982). Such a perspective would be able to account for the articulation of competences and capabilities as essential attributes of firms, in a comprehensive account of innovation systems (Bartzokas 2000).

Here the concept of the innovation system is explored, going back to that of "system". Drawing an analogy to the activity system perspective adopted by Porter (1996) and the concept of "resource commitment" advanced by Ghemawat (1991, 1999) the ontology of the innovation system is explored. It is suggested that the essence of the innovation system is that of an ensemble of resources committed by actors that are members of the system to innovation activities, which are interrelated. What distinguishes innovation activity systems from each other is, on one hand, the (emerging) strategic orientation of the innovation system and, on the other, the underlying mechanisms and (intangible and tangible) assets that drive individual actions and govern the interaction amongst agents. It is shown how system dynamics can provide a framework for modelling and simulation of innovation policy alternatives within the innovation system perspective.

The game-theoretic concept of co-opetition proposed by Nalebuff and Brandenburger (1996) is proposed as a conceptual framework that captures many of the intricacies of the interactions amongst actors in innovation systems. The rules of the co-opetitive game - as they are conceived, consciously or not, in the mental models of actors about reality - contribute to the formation of behavioural and cognitive regularities, forming the institutional foundation of system behaviour and performance. The evolution of the innovation system is conceived as a process that affects both the resource base of firms as well as the cognitive and institutional endowment of the innovation system. Alignment of innovative behaviour is considered to be emerging from the interaction of individual actors amongst themselves and with policy initiatives.

2 What is "systemic" about innovation systems?

The adoption of the term "innovation system" has been swift; one reason probably being that it seems so obvious. Freeman himself – who introduced the term (Freeman, 1987) – traces it back to the notion of system in the German tradition and List in particular. However, there seem to be very little research on the systemic nature of innovation systems. Park and Park (2003) have stressed this in an attempt to explore the issue (I discuss their approach below).

The term system implies two things: structure and interaction. These have been picked up by most researchers. In the seminal work led by Nelson (1993, ed.) the emphasis was given on the interaction between formal institutional entities (firms, government, universities and research establishments) and the structure of S&T activities. Lundvall (1992, p13) was assuming that "basic differences in historical experience, language, and culture will be reflected in national idiosyncrasies in: internal organisation of firms; inter-firm relationships; role of public sector; institutional set-up of the financial sector; R&D intensity and R&D organisation". The Scandinavian school which his book represented was more explicitly oriented towards the exploration of the institutional

"soft-wiring" of the innovation system (Johnson, 1992). Emphasis was given to the nature and significance of inter-firm interactions, user-producer ones in particular.

Still, the systemic nature of innovation systems has been essentially unexplored. In their study, Park and Park (2003) while raising the issue of systemic behaviour they revert to a description of regressions and possible regularities, which they do not support with any plausible causality. Indeed, they also fail to address the ontological perspective of the systems approach.

The systems thinking tradition provides for a conceptual framework that brings clarity and operational meaningfulness to the term (Senge, 1990). The emphasis is on the nature of interaction between the elements of the system. Circular causality, through feedback brings forth two important systemic properties. First, it is the root of dynamic complexity and the reason that we find it difficult to come to terms with delays in system behaviour. Second, behaviour emerges - in a transcendental mode (Lawson, 1997) – from the interaction of the elements of the system. Both these properties contribute to the counter-intuitive character of systemic behaviour. Simplistic or "linear" approaches to policy (that often relapse to push measures) cannot address the issues of innovation and development as they assume a 'black box' approach that ignores the internal structural dynamics that give rise to the emergent behaviour. Hence, performance exhibits non-linearity.

In social activity systems – as well as in most technical and natural ones – behaviour is governed by fairly simple laws, but its manifestation is usually far from straightforward. This happens because the rules determine how actors will act depending on external conditions, which in turn are the result of its actions. System-wide and individual performance feed back in the decision making process of individual agents, filtered through communication and perception. Individual behaviour evolves in tandem with the system's behaviour depending on the laws that govern the interaction amongst the elements of the system and with the external and system wide conditions. Underlying the rules of behaviour we may identify a dominant (cognitive) ideology that reflects a perception of reality, i.e. how things are and what should be expected as a result of individual actions. A useful research hypothesis might be that discontinuity, of a paradigmatic nature, could occur if the gap between (perceived) reality and expectations is sufficiently wide and other (subjective) conditions are in place.

Thus, a systems view on innovation systems should take a different angle. One needs to define not only the boundaries of the system, but also to clearly distinguish between different levels of system structure and performance. Simplistic aggregations simply obscure the picture rather than clarify it. Comprehension of a system is built bottom up, looking at the elements and the laws of interaction. Both are subject to change. A system evolves according to its internal structure and its interaction with its environment.

It follows that for the concept of innovation system to be meaningful – at a national, sectoral, regional or technological context - it should exhibit some idiosyncratic behaviour (that would result in specific and sustained performance) which would be attributed to the underlying laws of interaction, i.e. the institutional 'wiring' of the system (the social technologies, as Nelson -2002- calls it) that governs the interaction of its elements.

The behaviour of the system as a whole should emerge from the interaction of its elements. Thus, a normative framework could be developed, focusing on the interventions at different levels, with a bottom-up approach at its core.

3 Analysing the innovation system

Central to the concept of system is its goal-seeking nature. What distinguishes an innovation system from a "simple" production system would be its innovation-aiming nature.

Starting from Porter's (1996) view of the firm as a system of activities, one may define an innovation system as a system of activities that interact with the aim of innovation. Porter's contribution is significant for a reason that usually escapes attention: he implies emergence - i.e. that competitive performance is the result that emerges from the interaction of the elements of the system and that the structure of the interaction is important – denouncing simplistic and linear views that attribute competitiveness to single factors and linear causations. At the same time he put at the centre of his analysis a view of competitiveness as fit, implying that performance (and behaviour) is context specific (the system is open).

The activity system view had two drawbacks. It did not explain how the activities and their combination came to differ (the link to the resource-based view was weak). Also, it was unclear about the way in which these activities (and the resources that supported them) evolved. Ghemawat (1999) provides a powerful framework that integrates the two perspectives. He suggests that activities take place based on the resources that are committed to them. Resource commitment takes place according to expectations and past experience. Strategy involves making choices on where to commit resources to. In an earlier work, Ghemawat (1991, Ch. 3) argued that attention should be focused on commitment intensive strategic choices. Strategic choice matters when it considers where resources should be committed, i.e. how strategy will be implemented, as well as where to compete, i.e. why resources should be committed in a specific way. The latter sets the reasoning that will guide resource commitment. Ghemawat's perspective is also taking a view of strategy and competitiveness as fit. He goes on to argue that the effectiveness of the choices and resource commitments made depends on the responses of other stakeholders in the value system (Ghemawat, 1991, Ch. 5) in a repeated game.

Returning to innovation, the view taken here is that innovation occurs through the purposeful commitment of resources to innovation related activities (Figure 1). These may vary, from long-term R&D to the simple adoption of process technology, depending on how offensive or defensive the innovation strategy is. Innovation related activities may involve design, R&D, production facilities investment, sales and marketing, quality management and so on. They may also involve commitment of resources to externally controlled activities, e.g. a university laboratory or a subcontractor. Resource commitment is also important with respect to the nature of innovative activity and its locus. For example, Pisano (1997) showed how different strategies in innovation activities lead to different types of competitive advantage that fit in different competitive landscapes; the strategies where manifested by the variations in the commitment of resources to product and process R&D and learning by doing (learning-before-and-after doing).

The dynamic modelling of resource commitment to innovation activities through system dynamics provides for the ontologically accurate representation of innovation activities that is compatible with the evolutionary economics framework and resource-based view of the theory of the firm adopted here. Resources are accumulated and are on the whole specialised with respect to the innovation activity they are committed to. Feedback mechanisms are identified in the formation of strategic choices regarding commitment; they also provide the basis for path-dependent behaviour.

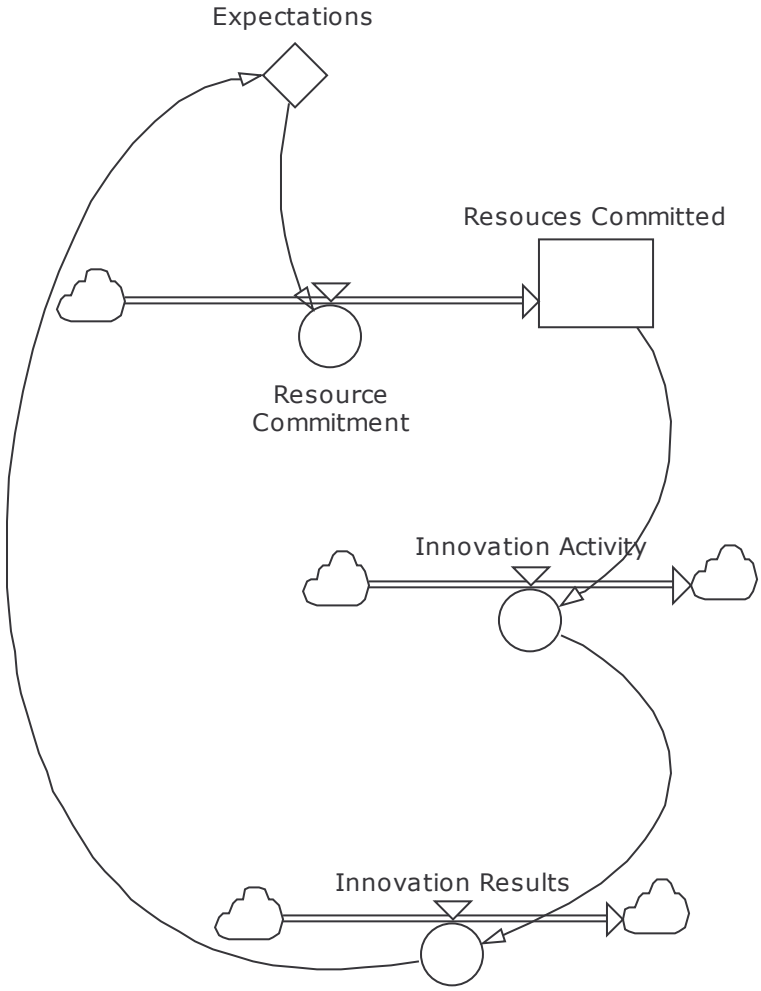

Figure 1: Resource commitment to innovation activities – a SD view

Still, firms operated in a specific context. In the innovation system literature the interaction between actors of the innovation system has a prominent role. Special attention has been given to the interaction between the S&T infrastructure and industry as well as to the interaction between firms (especially user-producer interaction). However, the reasoning and governance of these interactions seems to have been rather under-explored.

The systemic nature of technology renders the effectiveness of any commitment to innovation activities dependent on the actions of external stakeholders. They may be firms, financial institutions, research establishments, government agencies, international

bodies, local government, labour unions, NGOs and so on. Firms may interact with each other upstream and downstream the value system as well as horizontally linked with respect to the specific innovation. Stakeholder commitment may involve complementary assets (Teece, 1987), the investment in the development of complementary technology artefacts (as in the case of software and hardware) or complementary capabilities (marketing, system integration, design, maintenance, after sales support etc). This is an indicative list that aims to show the diversity of interdependencies. It neither exhaustive nor does it imply that the examples are mutually exclusive. Complementarities extend beyond the commercialization and production spheres. They include technological capabilities in R&D and product-system development which should develop in complementary trajectories.

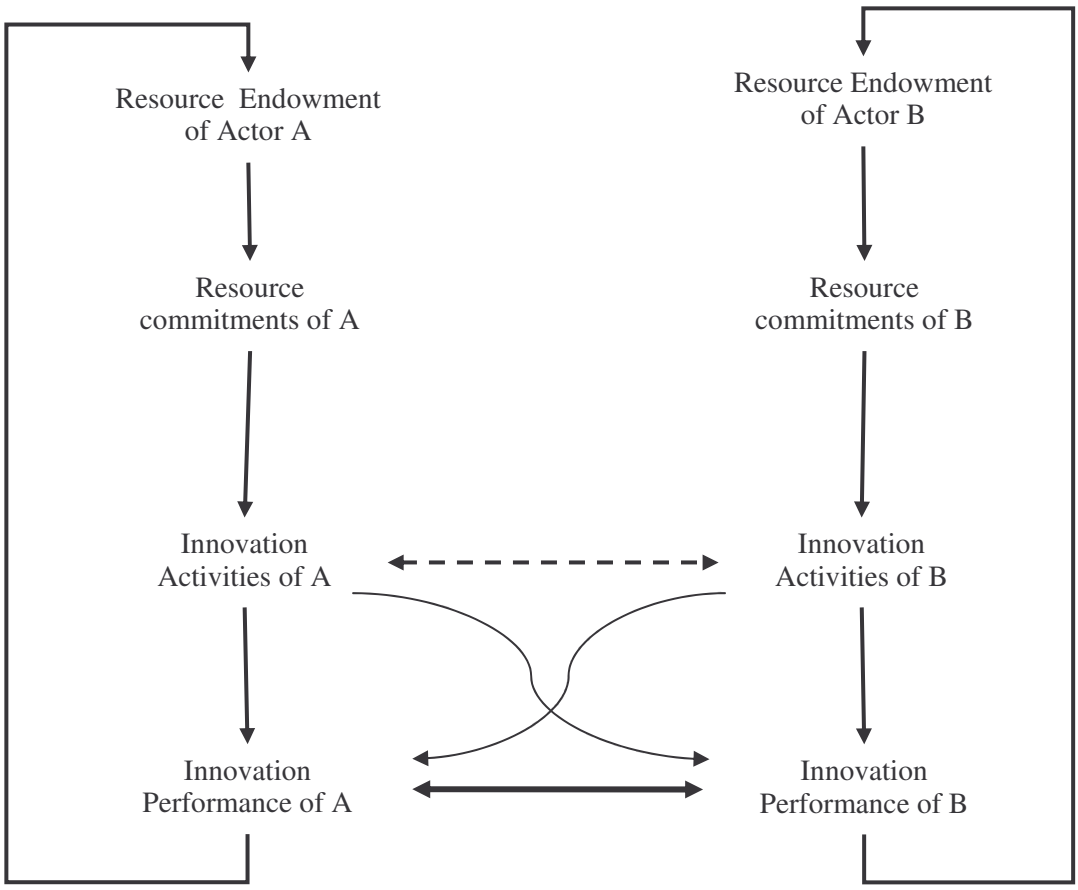

Figure 2: Interdependencies and Interactions in the Innovation System

It ensues that the actors engaged in direct or indirect interaction, via their innovation related activities, are subsystems of a broader system of innovative activities that we may term an innovation system. System performance may be measured as the sum of individual performances, but the latter depend on the former. Economies of agglomeration, networking, complementarities and synergies contribute to the effectiveness and performance of individual courses of action. Some types of resources may be of common nature, e.g. financial, skills, S&T infrastructure. They may also be measured as an indication of innovative activity, but, at the end of the day, the economic performance of firms in the competitive arena will be the one that matters

most (Of course, other activities, such as research conducted by public S&T organizations for distant partners, may also contribute to the welfare of society as a whole, but it is only indirectly linked to the innovative performance of the innovation system – albeit often in a significant way).

So at the core of an innovation system lie a set of actors that constitute interrelated systems of resources committed to activities. Their resources and activities are complementary and synergistic to each other's contributing to the overall performance of the system through individual performances (Figure 2). This may be called the hard element of the innovation system, although resources are both tangible and intangible.

4 The innovation system as a stage of co-opetitive games

A critical question that remains is how the choices of individual actors are aligned in specific innovation trajectories. In order to provide a convincing and constructive perspective of the mechanisms which govern the interrelations amongst the commitments of individual actors it is necessary to provide a framework of analysis that relates their actions to their worldviews. In other words, the choices made by actors within an innovation system are the result of their mental-models about the environment in which they operate. It is suggested here that, the conceptualisation of the interactions amongst actors in an innovation system as co-opetitive games provides for a cognitive-decision making framework that encapsulates most of the observations made in the previous section and allows for a dynamic view of these interactions.

Technological and activity complementarities suggest that firms and stakeholders in general, are engaged in games of co-opetition (Nalebuff and Brandenburger, 1996). They cooperate (explicitly or tacitly) in order to leverage the value and effectiveness of their own resource commitments and they compete for the appropriation of rents that result from the use of their innovations. These interactions take the form of games that are repeated. At every stage participants have to decide whether they will renew their commitment to specific arrangement of complementarities or they will seek to establish (bet on) a new one (Figure 3). This may arise because technology or other conditions may have changed (internally or externally to the co-opetitive arrangement), so stakeholders expect that a new architecture of interactions and interdependencies will be more fruitful. At every stage each player seeks to sustain or improve its bargaining position, i.e. to make it more sustainable or dominant.

The games actors act upon are socially embedded in two senses. First, embeddedness is the result of social role and status (Granovetter, 1985) as well as value complex, model of reality, repertoire of acts and routines (Burns et al., 2001); both contribute to action that is governed by subjective views of techno-economic situations and the prospect of the outcome of specific innovation action. Second, embeddedness implies that actors are involved in more than one game situation at the same time and may choose a course of action that is in their knowledge that it is suboptimal (Tsebelis, 1990). So, a firm will choose whether to invest in the development of a technology, product or process depending on her view of the competitive situation as well as the possible actions of complementors, the set of available options and experience on the behaviour of complementors and the effectiveness of past choices. This mental model of reality will be assessed according to the value complex held by the firm. The whole process will be guided and biased by a set of routines that govern the cognitive and decision making processes of the firm. A larger firm may find itself in more than one similar situation at

the same time, involving different partners, competitive landscapes and technologies. Another example is that of a university researcher, who has to balance the commitment of resources between different objectives: cooperating with firms, collaborating as well as competing with colleagues in other departments or universities, investing resources for the attainment of departmental objectives, choosing between projects that may attract funding and ones that will yield publications and so on.

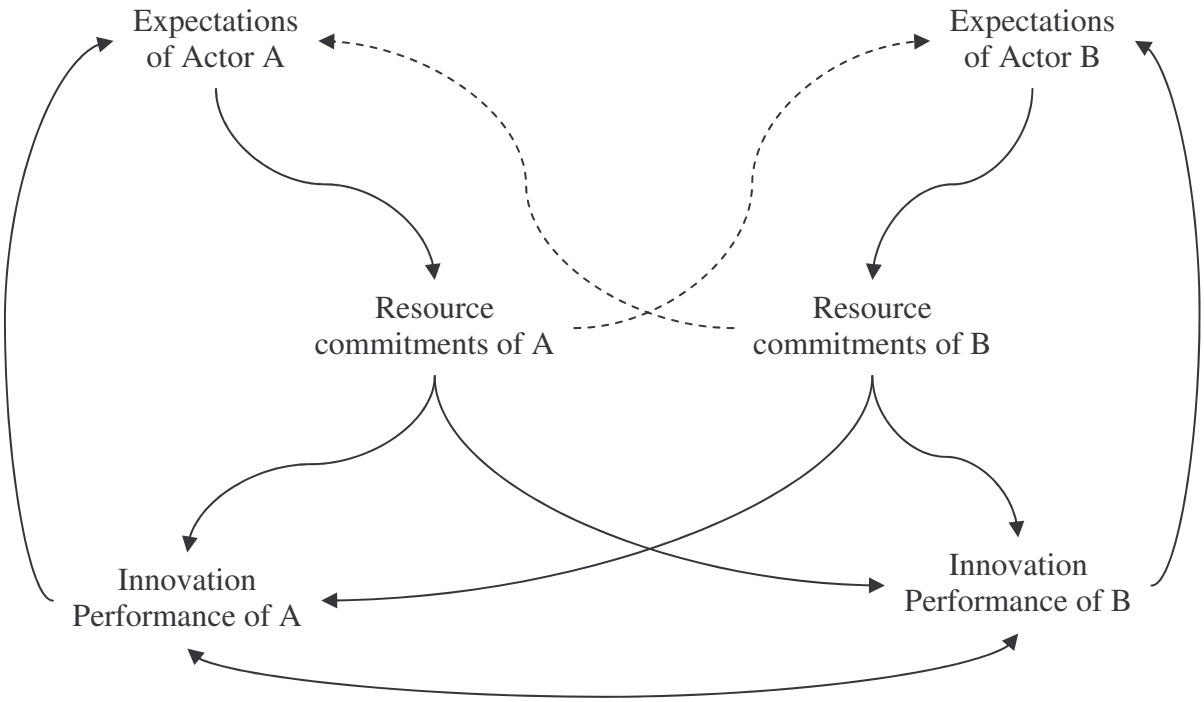

Figure 3: The co-opetitive game of innovation activities

Another characteristic of co-opetitive games is that they are usually nested. The opportunity for collaboration and the prospects for the extraction of benefits exist within a broader context in the value system. So, for example, two firms may develop complementary technologies for the construction industry, but the effectiveness of their action is also contingent on the actions of other actors and the conditions of markets upstream and downstream, all of which are not directly involved in the innovation effort itself, but affect the possibilities for success and often demand for a new game to be played.

Collaboration in innovation activities may often occur without any formal or conscious expression of it as intended. In many instances co-opetition is tacit, manifested only be the result of the actions of actors. Indeed, an actor may not need to announce its intention to take advantage of complementary actions of other actors. It will proceed with the intended commitment of resources to innovative activities based on the (conscious or subconscious) assumption that involved actors will act as expected, i.e. as complementors that will not threat the feasibility and sustainability of the investment made. Now resources committed are co-specialised to the innovation activities of both actors and the pace of their commitment is regulated by their expectation of both their returns on innovation and their co-opetitors future commitment of relevant resources,

which in turn is regulated by his corresponding expectations. The dynamics of commitment is becoming more complex as interdependencies affect path-dependence (Figure 4).

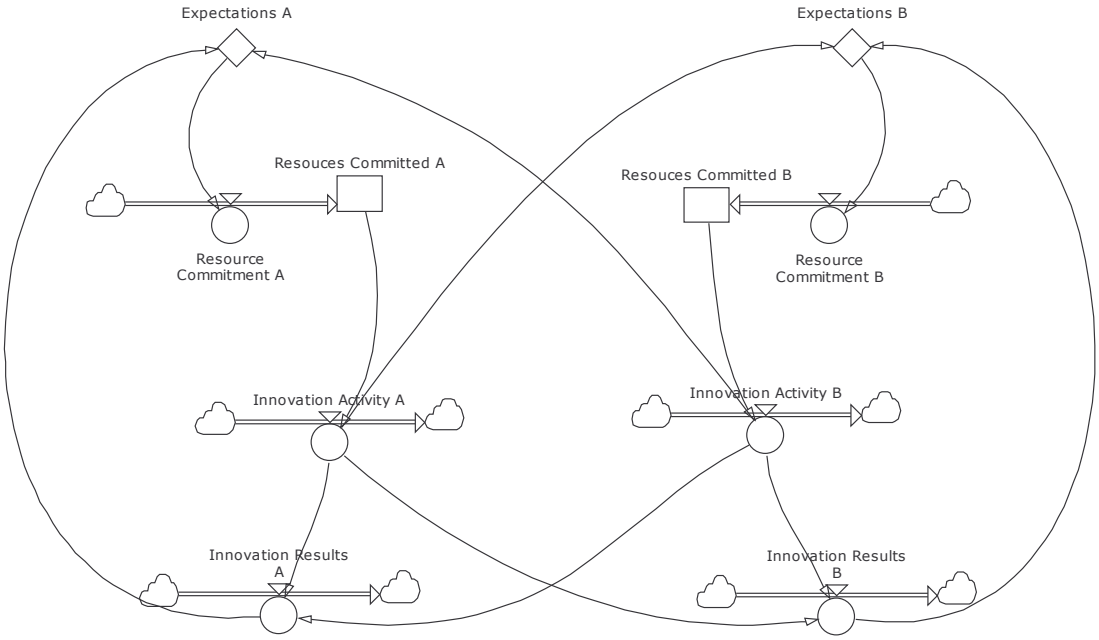

Figure 4: A System Dynamics view of the Co-opetitive Game of Innovation Activities

While firms and other stakeholders (tacitly) cooperate with each other to achieve innovation they are also engaged in an antagonism for the appropriation of its benefits. In view of the expected outcome firms will have to decide whether they will commit resources to a specific innovation or not. This decision will be influenced be the existing industrial organisation in the specific industry as well as the expected influence that a new technological development may have on that structure.

At the same time stakeholders will also rival for the allocation and orientation of upstream resources: public infrastructure in terms of transport and telecom networks, research and academic institutions and so on, as well as access to human capital, funding and upstream partnerships.

Thus innovation is a repetitive game where each participant (including those in the public sector) has to decide whether to commit to cooperate (either explicit or implicit). What distinguishes innovations systems from each other is how this game is played.

5 Mental models, routines, institutions: evolution through interaction-based learning

However, the main issue is – as in any game - the set of mechanisms that govern the continuance of these long-term alliances. Hence, the question that remains is how the innovation system becomes a whole (a system), in other words, what are the mechanisms that govern the alignment of resources and activities in specific directions.

The systemic and interdependent nature of innovation activities signifies that success (performance) depends on shared conceptualisation of technological and economic

prospects, which leads to the commitment of resources to specific activities at the expense of others. Choices rest upon assumptions on the actions of other stakeholders and expectations of return.

I suggest that, we may identify as core elements of the dominant ideology specific mental models, which represent actors' perceptions of economic reality and drive behaviour. They provide the "programming" for organisational routines of decision making on strategy and innovation. They form a set of underlying assumptions about reality. These assumptions contribute to establish expectations of actors, i.e. how the game is played: the rules of interaction, the nature of interdependencies and the behaviour of other actors. They are based on past experience as well as new knowledge. Still, insight on the significance of new developments (in technology, regulation etc.) is based largely on past experience. Thus, mental models constitute institutional 'core rigidities' (Leonard-Barton, 1995) which govern the behaviour of actors in the Veblerian form of 'general habits of action and thought'.

The mental models actors build about how the world is and operates are rather fixed. The fact that, within an innovation system, most people will have been through the same ideological and socialising mechanisms (especially education and industrial or professional associations) means that, it is highly probable that their views about how things are will converge. So, behaviour will tend to reinforce assumptions on others' behaviour and, consequently, expectations about them and the rules of the game. In the context of a co-opetitive game, co-specialisation will involve not only the development of technology and tangible assets, but also knowledge about each other and the competence to cooperate and compete with each other.

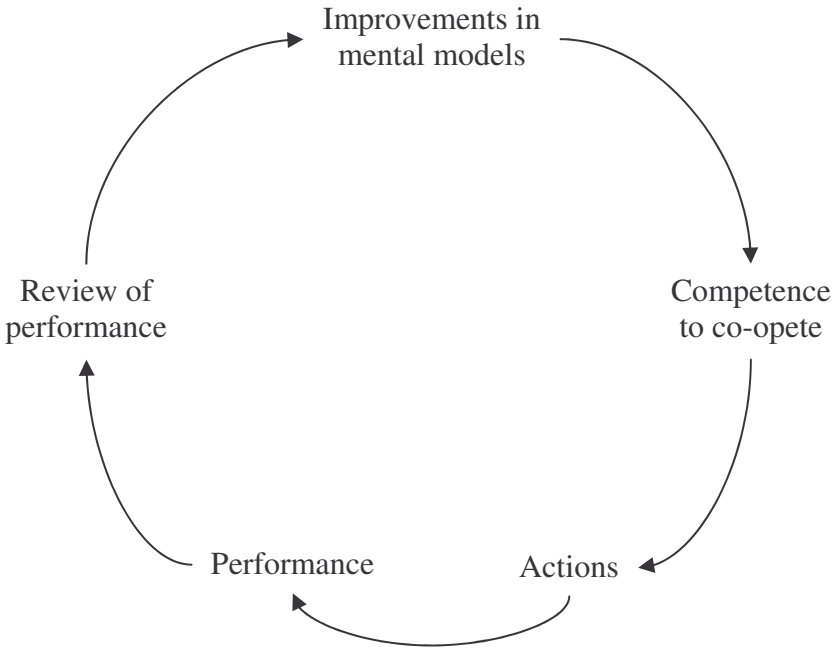

Figure 5: Single loop learning in a context of interaction

Hence, the idiosyncrasies that characterise an innovation system may be the result of an evolutionary process, where the set of heuristics of behaviour evolve in the context of

interactions specific to the innovative activities of firms. Co-opetition competences are developed on the basis of a single-loop learning process, where 'playing the game' contributes to improved comprehension of the dynamics of interaction involved and, thus, improved performance (in the specific context) (Figure 4). Path-dependence will contribute to the reinforcement of a cognitive trajectory that will facilitate interactive behaviour.

Challenges to the sustainability of the actors in the innovation system may result in significant revisions of the assumptions set that underpin their behaviour. Such discontinuous change may require either changes in innovation strategy of individual players or restructuring of the rules of interaction. Double-loop learning will result in the revision of mental models about the co-opetitive environment and changes in innovative behaviour (decision on the commitment of resources on innovative activities) will be based on new rational. Change is cognitive as well as behavioural. It leads to new norms, conventions and rules of thumb that form the new institutional framework of co-opetition.

Changes in the institutional soft wiring that drives behaviour may come as a result of external influences, such as changes in the behaviour of others or external –to the co-opetition interaction – factors such as new technological developments, changes in markets, regulations etc. Rules of behaviour differ, *inter alia* due to prior performance. Past behaviour is also an important factor in the formation of expectations for the future behaviour of stakeholders. The cause of change may be internal to the system, caused by change in the behaviour of one of the other actors or revision of the appreciative framework of the actor itself (Figure 5). A source of change, not portrayed here explicitly, may be the environment in which the game is embedded with respect individual players. For example, a revision of the priorities of government policy, or of the assessment criteria in a university will lead to new appraisal of the cooperative relations with firms.

The issue of embeddedness hinted above, illustrates the diversity of actors involved in an innovation system. This brings to the forefront the plurality of perspectives that will form their cognitive background, the asymmetry of assessments and the imbalances of power involved in the negotiation of the rules of the game. When behaviour is consistent or when changes in behaviour are negotiated then trust is developed amongst them. Maskell (1998) illustrates how trust may be sustained and reinforced via a set of institutions that are of a soft-informal nature and focus on the formation of expectations by actors (penalty for the betrayal of trust, compensation for conforming expectations, consensus seeking processes, visibility of actions). These however do not clarify how cooperation is achieved in the first place.

Indeed, the ability to navigate such a complex terrain of diverse agendas lies beyond individual competences. Nor is it simply a matter of shared mental models. It is a system competence that emerges from the interaction of individual actors (Lawson, 1999). It is a competence of sense-seeking (Coetzee, 2000) that relies on triple-loop learning mechanisms (Flood and Romm, 1996), i.e. mechanisms that facilitate the mutual understanding of diverging perspectives between individuals so that intelligent decisions are made on the basis of appreciation of others' priorities, objectives, assumptions and cognitive processes in general.

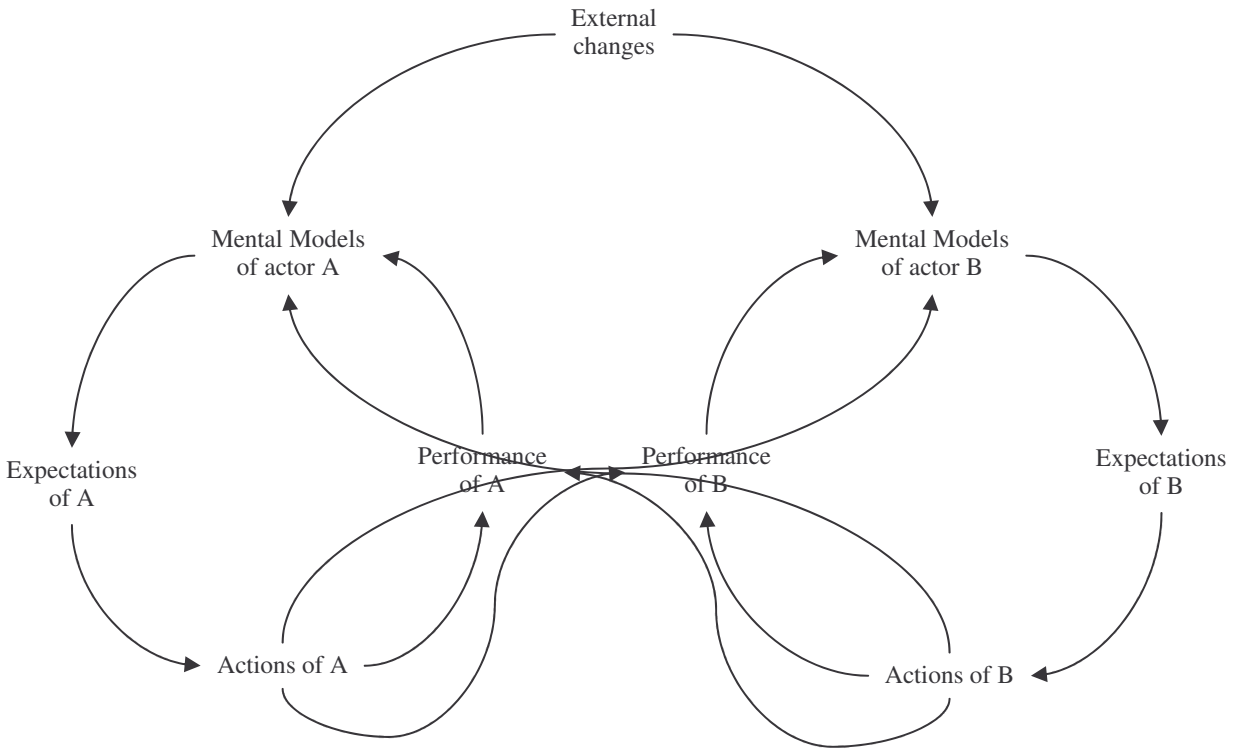

Figure 6: Double loop learning in a context of interaction

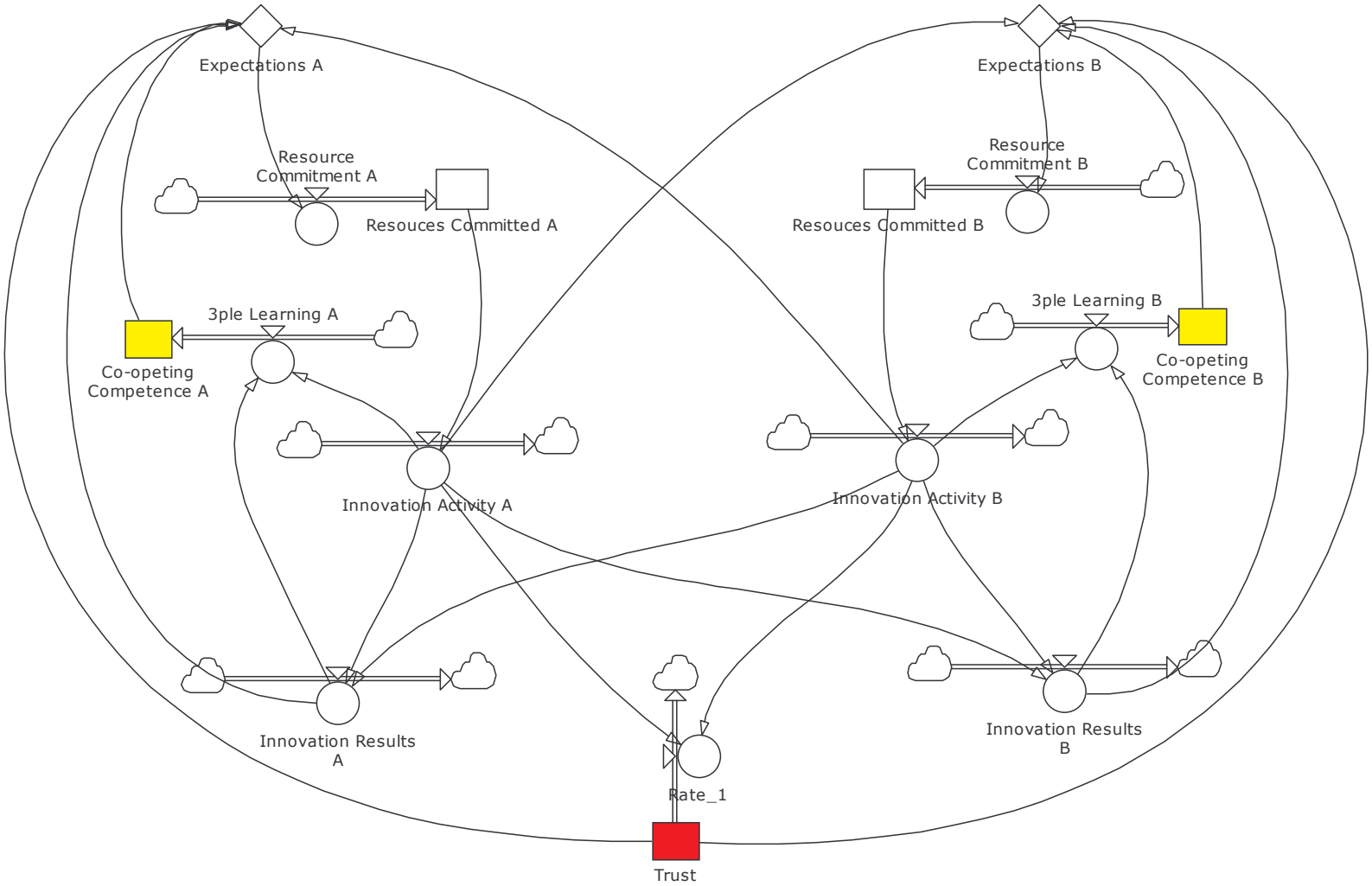

Figure 7: Triple loop learning and critical intangible system resources

Different innovation systems are endowed with different mechanisms that facilitate mutual appreciation. These are also part of the institutional framework. They range from negotiating to dialectical. In one end actors may adopt contesting negotiating positions, viewing the situation as zero-sum game or treat change as threat and seek to maximise individual payoff, or adopt short term perspectives. Such behaviour will increase mistrust and undermine future efforts to embark on more constructive engagement, leading to vicious circles of poor cooperative culture and, consequently, innovative performance. At the other end, a dialectical culture of openness and participation will facilitate mutual appreciation of positions and perspectives leading to consensual behaviour and conflict avoidance. It is obvious that triple loop learning reflects intensely on mental models as well as the ability of actors to take advantage of double-loop learning.

Accordingly, a new set of resources may be identified as critical in the evolution and performance of an innovation system. A new type of competence "to co-opete" appears important to the ability of organisation to appreciate their external environment – more specifically the nature and character of the dynamics of the behaviour of other actors. This competence is organisation and context specific; it leads to a set of expectations specific to the context it is build to appreciate. Also, the level of trust amongst actors is crucial parameter in the decision to commit resources in innovative activities, when the outcome from such a commitment depends on the complementary actions of other actors. While the level of trust may be modelled as a shared resource it is not so clear where co-opeting competences are organisation specific or are also shared, since they involve the development of a shared language or mode of communication. Still it is argued here that we may develop a system dynamics model of an innovation system that will be a powerful tool for analysis and innovation policy formation (Figure 7),

6 Alignment as an emergent phenomenon

In this paper I have presented a conceptual framework of innovation systems that sets at the centre the interactions between actors engaged in interrelated innovative activities. Central to my argument is that performance is the result of resource commitments to innovative activities. The question then is how these commitments are aligned in order to achieve the performance observed. Starting from the concept of co-opetition, I propose that the performance and behaviour of individual actors, as well as of the system as a whole, is based on a cognitive-institutional endowment that underpins routinised behaviour, leading to the emergence of idiosyncratic characteristics.

Alignment is facilitated by three different learning processes. Single-loop learning functions as a form of dynamic path dependence mechanism, which is based on the accumulation of the competence to improve performance within a given context of co-opetition. It allows for the tacit conformance to the rules of the game in tandem with improved comprehension of them. Tangible as well as intangible resources are developed through a web of interactions and commitments involving the negotiation of allocation, co-option and so on. Intangible resources involve trust as well as the rules (routines) that guide their behaviour and the mechanisms of negotiation amongst stakeholders. Within an established technological trajectory this institutional endowment will form part of the trajectory, embodying and guiding the individual choices of stakeholders.

Double-loop learning in a context of interaction and interdependence facilitates the renegotiation of the rules and conventions of co-opetition. Its effectiveness relies on the ability to reformulate the underlying mental models, as well as on institutional arrangements that enhance trust and support negotiation. In many cases mechanisms of mediation and dialogue are formally institutionalised in the form of associations, joint support centres, government programmes or authorities and so on. They contribute to the development of new shared assumptions, beliefs, norms, conventions and rules of thumb.

Another function of the institutional endowment is the governance of exploration and assessment of new technological opportunities and the resolution of future stakeholder roles. Triple-loop learning facilitates the changes in expectations of other actors' behaviour, contributing to better informed mental models, deeper appreciation of other perspectives and formulation of sustainable commitment decisions. Strategic intent is thus reached at from a more intelligent position with respect to the co-opetitive landscape.

These three sets of types of learning operate as mechanisms of stretch and leverage (Hamel and Prahalad, 1994) within games of co-opetition. As collaboration leverages resources in an inter-organisational framework, shared expectations operate as a means of stretch. This process is compromised by the antagonism both for upstream resources as well for the returns of their collective investment. Demand driven policy may play a key role in this process. Public procurement as well as public R&D programmes may provide both the stretch as well as the framework for the governance of the dialogue amongst stakeholders and the development of the institutional endowment. The case of MITI in Japan is probably the most documented, as a facilitator of triple-loop learning. Actors (firms as well as public bodies and S&T organisations) were involved in processes of developing common understanding of technological developments and prospects, emerging opportunities, as well as comprehension of the individual roles and perspectives of the other actors involved.

However, a shift is required with respect to the objectives and analysis of policy intervention, away from input-output perspectives to a more institutional and structural perspective, focused on the underlying mechanisms that govern interactions within an innovation system. This would require the exploitation of holistic intervention methodologies developed by the systems community (e.g. those advocated by Flood and Romm, 1996 and others mostly in Europe rather in the US).

The conceptual framework outlined above may also lead to a new typology of innovation systems, based on the mapping of the dynamics of the rules of interactions amongst agents. This necessitates a more pluralistic approach, which will be based on the representation of detailed causal diagrams characterised by feedback loops that will form a richer picture of the institutional endowments of innovation systems. System dynamics modelling provides a basis for the development of a framework of participatory and exploratory policy formation that also contributes to the learning process itself.

7 Conclusion

The approach proposed above aims to provide for a novel framework to innovation policy. Beginning from a bottom-up perspective based on the resource based view of the firm and economic activity, here the concept of resources is broadened to include

the cognitive and cultural elements that drive the formation of the institutional structure that governs economic action and performance. It provides for the understanding of "spontaneous coordination and organisational forms, such as networks and local clusters".

The aim has been to provide for a new direction of search for the institutional arrangements and leverage mechanisms that will support a bottom-up policy approach. It sets a cognitive culture dimension as the critical element that may provide for the analysis of a techno-economic environment that is characterized by intensifying connexity. The emphasis is on leverage rather than measures of direct impact, since the aim is a radical departure to a new ideological hegemony.

System dynamics provide the modelling and simulation framework that is compatible with the ontological requirements of critical realism and evolutionary approach. It addresses issues of path dependence, accumulation, interdependence and co-specialisation of assets, emergent behaviour and performance and so on. Also the role of intangible assets such as trust and competence and capabilities may be factored in and represented in a realistic and operationally fruitful manner.

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